UNCLASSIFIED

TECHNICAL MEMORANDUM

U.S. NAVAL APPLIED SCIENCE LABORATORY
FLUSHING & WASHINGTON AVES.
BROOKLYN, NEW YORK 11251

CRITICAL RADIANT EXPOSURES

FOR

IGNITION OF TINDER AND COMBUSTIBLE MATERIALS

(Part I - Wood)

DASA Subtask 12.009

Lab. Project 9400-12, Technical Memorandum 5

15 January 1965

PHYSICAL SCIENCES DIVISION

Approved: J. M. McGreevy

J. M. McGREEVY
Associate Technical Director

U. S. NAVAL APPLIED SCIENCE LABORATORY
Naval Base
Brooklyn, New York 11251

Distribution of this document
is unlimited.

Lab. Project 9400-12
Technical Memorandum 5

SUMMARY

Wood in six different forms was exposed to thermal radiation from simulated nuclear weapons pulses in the range from 65 kilotons to 100 megatons. Sawdust from weathered wood was most readily ignited, glowing ignition occurring at 6.4 cal cm^{-2} for a 65 kt pulse, and at 21 cal cm^{-2} for a 100 Mt pulse. Clean, unseasoned douglas fir, one-half-inch thick, was ignited to sustained flaming at radiant exposures of 31 and 68 cal cm^{-2} for yields of 1.2 and 108 Mt, respectively. Weathered douglas fir could be ignited only to short-lived afterglow which extinguished itself shortly after exposure.

Yellow poplar, clean, 1/16-inch thick, was ignited to sustained flaming at 33 and 71 cal cm^{-2} for pulses simulating weapon yields of 1.2 and 108 Mt, respectively; excelsior ignited at 29 and 53 cal cm^{-2} for the same pulses.

Sustained flaming of the unseasoned douglas fir is a significant finding which is contrary to previous experience. The heavy resin content of the specimens studied in these tests is obviously a factor.

TABLE OF CONTENTS

ADMINISTRATIVE INFORMATION

Ref: (a) Program For Determining Critical Radiant Exposures For Ignition Of Tinder And Combustible Materials, Naval Applied Science Laboratory, Lab. Project 9400-12, Technical Memorandum 2, 17 June 1964
(b) J. Bracciaventi, Ignition Of Newspaper And Cotton Cloth By Thermal Radiation From Nuclear Detonations, Naval Applied Science Laboratory, Lab. Project 9400-12, Progress Report 2, 11 September 1964
(c) S. Glasstone (Ed.), Effects Of Nuclear Weapons, U.S. Government Printing Office

The work described herein constitutes part of the U. S. Naval Applied Science Laboratory's programmed effort on the Effects of Thermal Radiation on Materials sponsored by the Defense Atomic Support Agency under Subtask 12.009.

The work reported herein was conducted by J. Bracciaventi under the supervision of W. L. Derksen, Senior Task Leader, and the general direction of T. I. Monahan, Head, Physics Branch.

INTRODUCTION

The objective of this program is to develop information for making estimates of the effects of thermal radiation on targets and materials of interest to the Department of Defense. The radiant exposures required to ignite tinder materials are of immediate interest in determining the incendiary effects of weapons on urban targets.

The details of the program were described in reference (a). Forty-six materials are under examination, divided into seven classes, which will be exposed to radiant energy pulses with irradiance histories simulating those from a nuclear detonation.

This memorandum covers the results of exposing wood specimens to laboratory simulated nuclear detonation pulses in the yield range covered by times-to-maximum-irradiance of 0.25 to 11 seconds.

Technical memoranda will be prepared on the results of each phase of the program. The final report, to be prepared upon completion of the program, will summarize the significant findings of the investigation; the data obtained should serve as input to improve and extend ignition prediction models. The final report will also contain a documentation of the important physical properties of the materials such as weight, thickness and absorptance. The data will be generalized so as to allow reasonable interpolations for variations, within each class, in the material and exposure parameters. Ignition data for newspaper, which were reported previously in reference (b), will also be included.

DESCRIPTION OF SPECIMENS

The materials exposed were as follows:

1. Douglas fir, clean, unseasoned. The specimens were furnished by the NASL carpenter shop. They were cut to 2 1/2 x 2 1/2 x 1/2 inches, the surfaces exposed as cut, with no effort at smoothing.

2. Douglas fir, weathered. The specimens were cut from a severely weathered 14 x 14-inch timber which had been exposed to the elements at the New York Naval Shipyard for several years. The surfaces were deeply cracked and darkened. The specimens showed no evidence of loose grime or grease. The specimens were cut to 2 1/2 x 2 1/2 x 3/4 inches. Thinner specimens could not be cut because cracks in the surface were frequently 1/2-inch deep. The grain on the surface of most of the specimens was raised to provide thin edges. Specimens with nail holes and punky areas were available.

3. Yellow poplar. The specimens were cut from strips taken from two used fruit baskets to 2 1/2 x 2 1/4 x 1/6 inches. The wood was identified as yellow poplar by the U. S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, Wisconsin. All the exposed specimens were clean and unstained; some had holes where staples had been removed.

4. Excelsior. The excelsior was taken from three different shipments of equipment for which it was used as packing. The strands ranged from thin thread-like pieces up to coarser strands about 1/32-inch thick. It appeared clean and free of foreign material. In exposing the material to thermal radiation, it was lightly packed into open-ended cubes of perforated metal measuring 2 x 2 x 2 inches.

5. Sawdust. The sawdust was accumulated during the cutting of weathered douglas fir specimens. For the exposures, the sawdust was packed into

aluminum tubes 1 inch in diameter and 1 1/4 inches deep. The sawdust plug was pushed slightly out of the tube at the end being exposed.

6. Punky Wood. The punky wood was provided by U. S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, and was identified as douglas fir. It was exposed in the form of sheets ranging from 1/4 inch to 1 inch thick. Exposures were made on faces parallel to the grain and perpendicular to the grain. Small chunks and powdered punk were also packed into aluminum tubes 1 inch in diameter by 1 1/4 inches deep.

PROCEDURE

The wood specimens were exposed to radiation from a carbon arc image furnace whose shutter was programmed to provide an irradiance history similar to those from nuclear detonations. The carbon arc image furnace utilizes 11-mm high intensity carbons at the primary focus of an ellipsoidal mirror with a 24-inch aperture. The radiation from the arc is concentrated at the secondary focus of the ellipsoid, where the exposures are made. A radial vane shutter in the converging beam is driven by an appropriately shaped cam powered by a constant speed motor whose speed can be varied over a wide range to provide different pulse lengths. The duration of the pulse is further controlled by a leaf shutter just in front of the exposure plane, the shutter being opened at time, t_o, and closed at 8.0 t_{max}. The irradiance history up to the cut-off time is similar to the generalized

nuclear detonation pulse given in reference (c). The radiant exposure produced by such a pulse when not arbitrarily cut off is

$$Q = 2.6\ H_{max}\ t_{max}\ \text{cal cm}^{-2},$$

where H_{max} (cal cm^{-2} sec^{-1}), is the irradiance maximum which occurs at time, t_{max} (sec). The radiant exposure delivered by the laboratory simulated pulse with cut-off at 8 t_{max} is approximately 80 per cent of the radiant exposure which a field pulse not arbitrarily cut off would deliver. The results reported herein are in terms of the total pulse, the radiant exposure given is equivalent to that specified for thermal radiation received at a distance from the burst. In making comparisons of the results reported herein with those reported elsewhere in the literature for which the pulses were cut off arbitrarily, a proper accounting of the radiant exposure of the cut-off portion of the pulse should be made even though it is not expected to contribute to the effect. Most effects on materials, such as ignition, occur well before the 9 t_{max} cut-off time used at NASL, especially for the critical, or threshold, radiant exposure for that particular effect. The maximum surface temperature of a solid will occur at 1.6 t_{max} while maximum temperatures in thin slabs will occur soon thereafter because of irradiation at the attained temperatures.

The maximum irradiance desired is selected by placing perforated metal attenuating screens in the beam between the mirror and the sample. The irradiance is measured by a 0.5 cm aperture copper button calorimeter in the exposure plane with the radial vane pulsing shutter in the

full-open position. Generally, the highest irradiance available at the exposure plane with the image furnace used in this portion of the program is 15 cal cm^{-2} sec^{-1} for stable operating conditions of the arc. The charred area on a specimen in the focal plane is roughly circular, having a diameter of 1.7 cm at the radiant exposure for which charring is first visible. The charred area increases as the radiant exposure increases. A scan of the focal plane with an aperture of 0.1 cm diameter shows that the distribution falls off with radial distance as follows:

Per Cent of Maximum	Diameter (cm)
100	0.0
90	1.04
75	1.68
50	2.80

For the exposures the pulse irradiance-time characteristic is chosen to simulate the desired weapon yield. The maximum irradiance is adjusted by means of attenuating screens until the threshold appearance of the effect under study is bracketed sufficiently to specify to within ±5 per cent the value of irradiance (from which the critical radiant exposure is calculated) for which the effect is observed in 50 per cent of the specimens.

During the exposures to thermal radiation, an observer watched for evidence of transient flaming of the specimen. The specimen was examined in its holder immediately after exposure for afterglow and sustained flame. Transient flame was reported when the observer saw flames develop

during any part of the exposure episode but which extinguished at or prior to cut off of the pulse. In all cases, however, the transient flame was clearly extinguished before the pulse cut-off even for radiant exposures considerably greater than the critical exposure. Afterglow was reported when sparks or glow persisted on the specimen after the cut-off. The glow might be short-lived for only fractions of a second after cut-off, or might persist long enough to consume the unexposed portions of the specimen. Sustained flame was reported when flaming persisted after the exposure was cut off. Again the flame might be self-extinguished, but generally it consumed the unexposed portions of the specimen.

RESULTS

The results of the exposures are given in Table 1. The pertinent data listed are: t_{max}; the yield simulated based on $t_{max} = 0.032\ W^{1/2}$; the threshold, or critical, radiant exposure for 50 per cent effects for transient flame, afterglow and sustained flame; and the irradiance maximum associated with that value of radiant exposure. The number of specimens exposed and the range of radiant exposures for each value of t_{max} is also listed.

The following additional facts concerning the exposures are reported.

<u>Douglas fir, clean, unseasoned, 1/2-inch thick</u>

In general, wood in this thickness has been found to ignite during the exposure, but there has been no record of sustained ignition

after cut-off. However, in this investigation many of the specimens from this lot of wood were found to sustain ignition for long periods (many minutes) after exposure. Burning was usually vigorous, accompanied by sporadic flame jetting. Resinous exudations were noted on specimens that were given exposures less than those required to cause flaming. Not all specimens, even for exposures greater than the critical radiant exposures listed for flaming, were ignited to sustained ignition; some flamed only during exposure. It required approximately the same radiant exposure level to produce either transient or sustained flaming. In order to check this finding, a supply of seasoned douglas fir will be exposed to a similar exposure regimen to determine if radiant exposures in this time range will produce sustained ignition. Overlapped pieces of douglas fir were exposed to radiant exposures ten per cent less than those required to ignite the flat surface. No significant decrease in ignition radiant exposure was found.

<u>Douglas fir, weathered, 3/4-inch thick</u>

Sustained flaming ignition was not detected on any specimen exposed. Sustained glowing ignition occurred where the grain was lifted from the surface. The flowing was relatively short-lived, usually on the order of one or two seconds after pulse cut-off, and was always self-extinguished. Deeply creviced specimens, splintered areas and nail holes were not noticeably more vulnerable, nor was glowing more persistent on these specimens.

Yellow poplar, 1/16-inch thick

No transient flaming effects were observed; once ignited, the specimen was completely consumed. Nail holes and cracked specimens did not prove to be more vulnerable.

Excelsior

Transient flaming did not occur. The afterglow was easily kindled into sustained flame after exposure, caused by slight air motion on the exposed face.

Sawdust

The sawdust was ignited to sustained ignition only by the pulse whose time to maximum irradiance was 1.1 second. The afterglow was not self-extinguishing but very slowly consumed the entire sample.

Punky Wood

The punky wood when exposed in solid pieces proved to be difficult to ignite. The exposures were accompanied by emission of dense smoke and small particles from the exposed surface. The very finely powdered punk mixed with small chunks was ignited to glowing more readily. In both cases the afterglow proved to be difficult to extinguish.

The radiant exposures for ignition for each material are depicted graphically in Figures 1 through 6.

FUTURE WORK

Simulated weapons pulse exposures on the balance of the materials outlined in reference (a) are under way. A report on the results of exposure of cotton, wool and synthetic fabrics will be issued shortly, to be followed by reports on paper and miscellaneous materials. The final report will include all these results, including those of studies of the effect of area of exposure on materials in each class. The work on wood will be extended to used and weathered shingles, and clean, seasoned lumber.

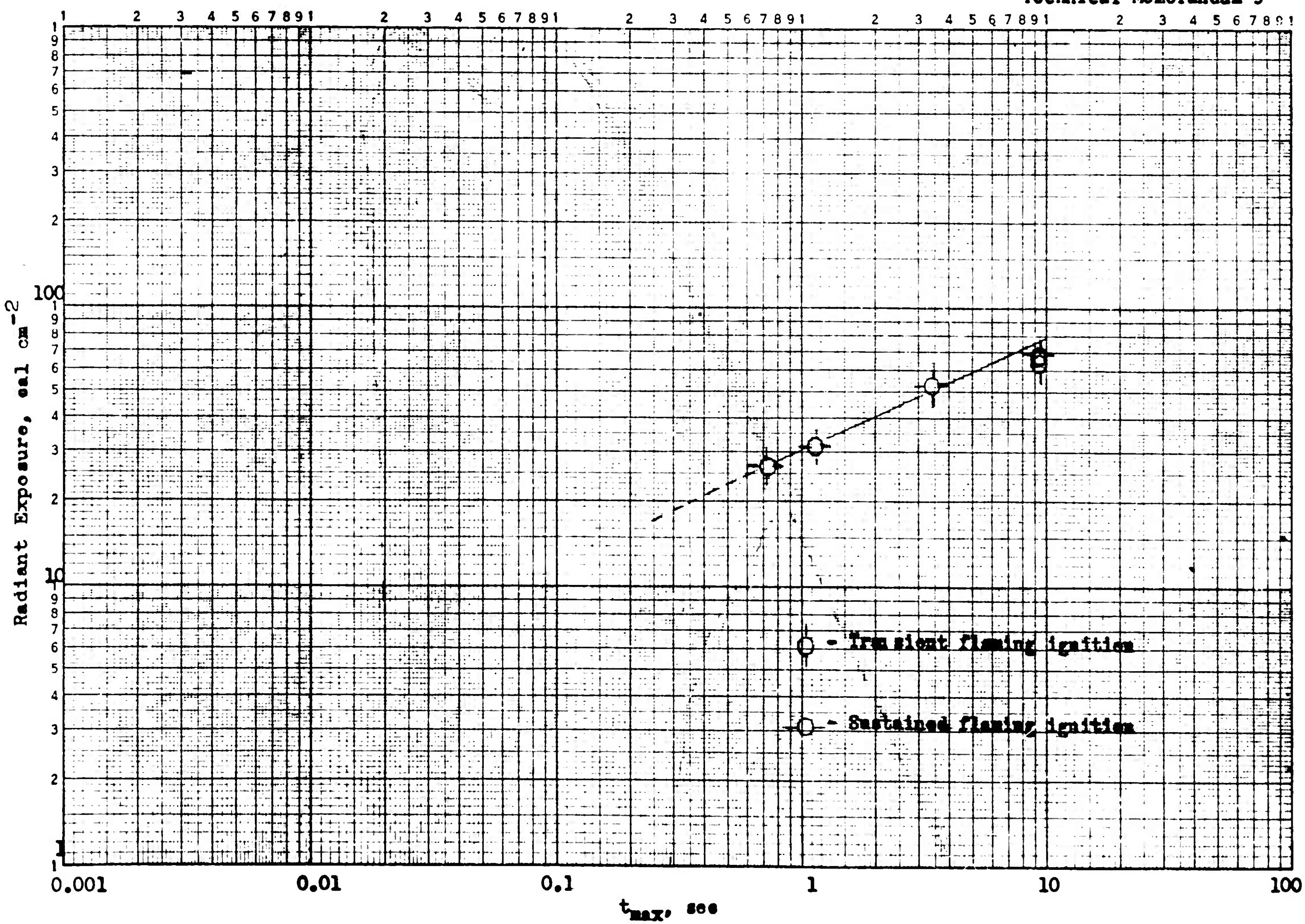

Figure 1 - Radiant Exposure To Ignite Douglas Fir, unseasoned, clean, 1/2-inch thick.

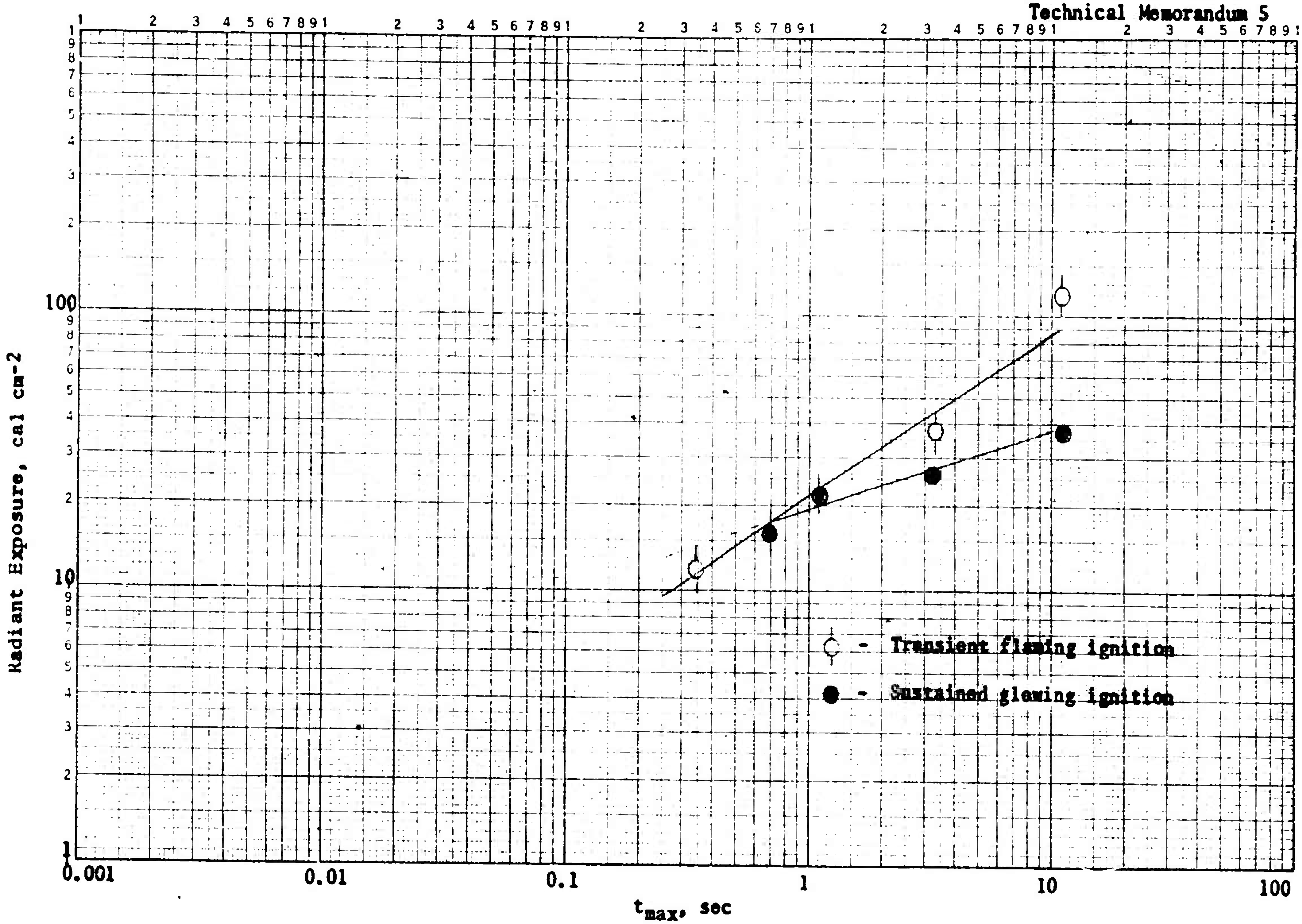

Figure 2 - Radiant Exposure To Ignite Douglas Fir, weathered, 3/4-inch thick.

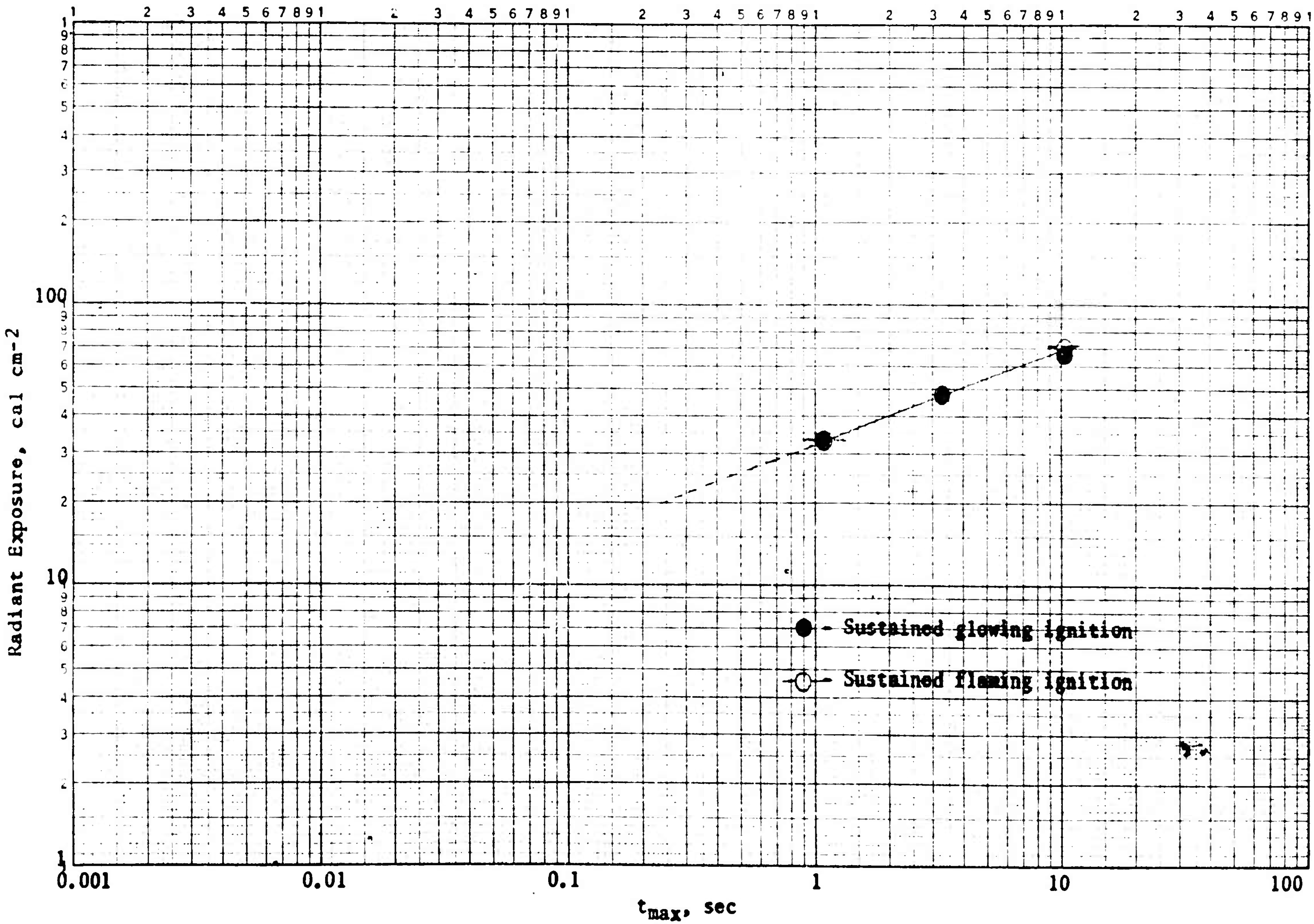

Figure 3 - Radiant Exposure To Ignite Yellow Poplar, 1/16-inch thick.

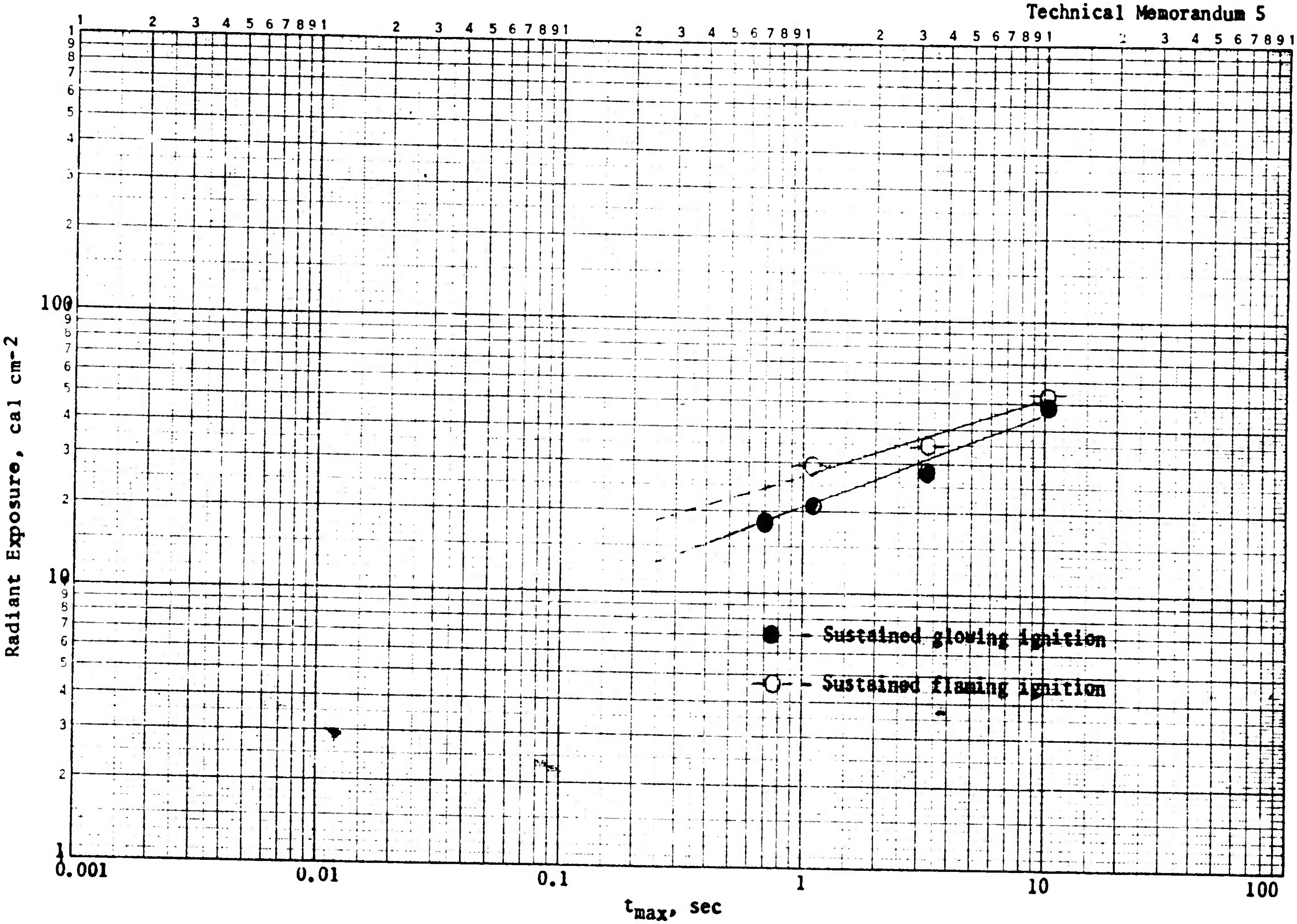

Figure 4 - Radiant Exposure To Ignite Excelsior, used, clean.

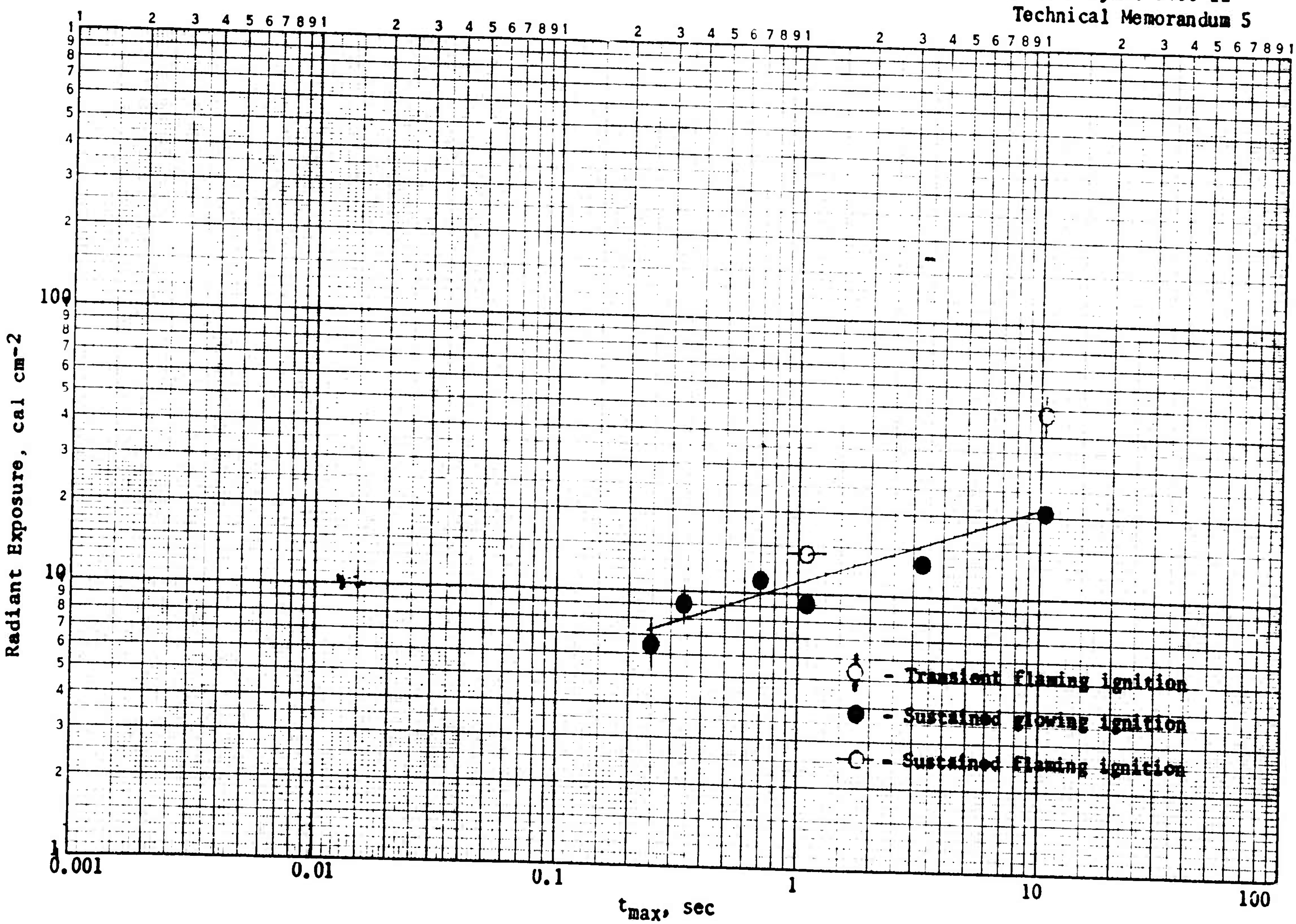

Figure 5 - Radiant Exposure To Ignite Sawdust,
(from weathered Douglas Fir).

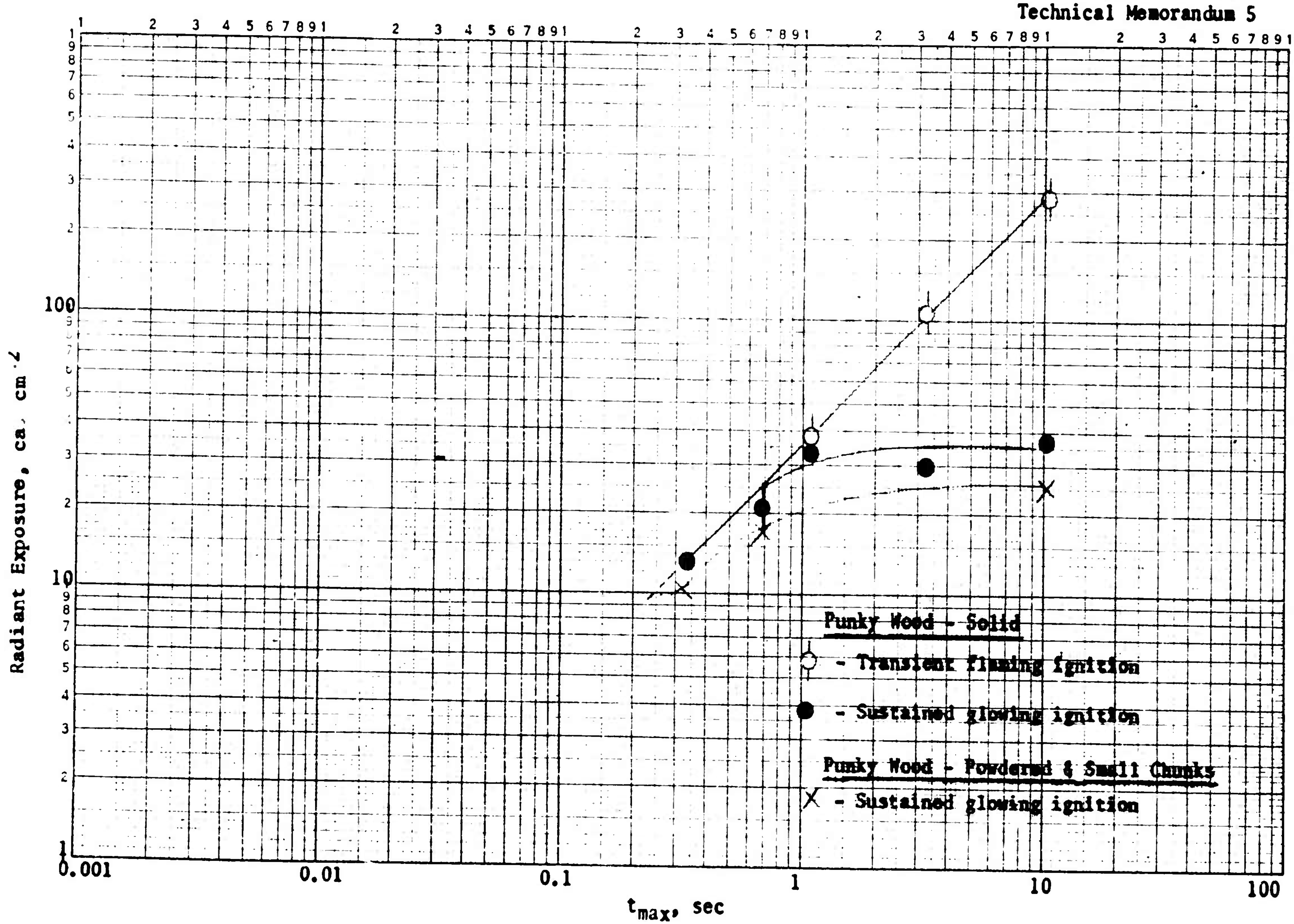

Figure 6 - Radiant Exposure To Ignite Punky Wood, Douglas Fir.

TABLE 1

RADIANT EXPOSURES BY NUCLEAR DETONATION PULSES T(

	t_{max} (sec)	Yield(1) (kt)	Transient Flame H_{max} (cal cm^{-2} sec^{-1})	Transient Flame Q(2) (cal cm^{-2})	Afterglow H_{max} (cal cm^{-2} sec^{-1})	Afterglow Q(2) (cal cm^{-2}
Douglas Fir (clean fresh surfaces) 1/2-inch thick	0.25	65	No ignition for Q = 9.2 cal cm^{-2}			
	0.34	115	No ignition for Q = 13 cal cm^{-2}			
	0.70	480	13	26		
	1.1	1,180	11	31		
	3.3	10,700	5.9	51		
	9.1	83,000	2.7	64		
Douglas Fir (weathered) 3/4-inch thick	0.25	65	No ignition for Q = 9.2 cal cm^{-2}			
	0.34	115	13	12		
	0.70	480	8.8	16	8.8	16
	1.1	1,180	7.6	22	8.0	23
	3.3	10,700	4.3	38	3.0	26
	11.3	127,000	11	120	13	38
Yellow Poplar (used, fruit baskets, clean), 1/16-inch thick	0.25	65	No ignition for Q = 9.2 cal cm^{-2}			
	0.34	115	No ignition for Q = 13 cal cm^{-2}			
	0.70	480	No ignition for Q = 26 cal cm^{-2}			
	1.1	1,180				
	3.3	10,700				
	10.5	108,000			2.5	67
Excelsior (used, clean)	0.25	65	No ignition for Q = 9.7 cal cm^{-2}			
	0.34	115	No ignition for Q = 13 cal cm^{-2}			
	0.70	480			9.9	18
	1.1	1,180			7.3	21
	3.3	10,700			3.3	28
	10.5	108,000			1.8	48
Sawdust (from weathered Douglas Fir)	0.25	65	9.7	6.4	9.7	6.4
	0.34	115	10	9.0	10	9.0
	0.70	480	6.1	11	6.1	11
	1.1	1,180			3.2	9.1
	3.3	10,700			1.5	13
	10.5	108,000	1.3	48	0.8	21

TABLE 1

JCLEAR DETONATION PULSES TO IGNITE WOOD

	Afterglow		Sustained Flame		No. of Specimens Exposed	Range of Radiant Exposures	
	H_{max}	$Q^{(2)}$	H_{max}	$Q^{(2)}$		Low	High
	(cal cm^{-2} sec^{-1})	(cal cm^{-2})	(cal cm^{-2} sec^{-1})	(cal cm^{-2})		(cal cm^{-2})	
m^{-2}					3	-	9.2
-2					3	-	13
					15	13	27
			11	31	16	22	43
			5.9	51	22	39	57
			2.8	68	11	51	69
m^{-2}					3	-	9.2
					9	9	13
	8.8	16			29	14	27
	8.0	23			14	20	43
	3.0	26			28	38	128
	13	38			33	28	166
n^{-2}					2	-	9.2
-2					4	-	13
-2					3	-	26
			12	33	15	32	43
			5.5	48	14	45	64
	2.5	67	2.6	71	20	65	114
1^{-2}					3	-	9.7
-2					3	-	13
	9.9	18			10	18	26
	7.3	21	10	29	18	20	33
	3.3	28	3.9	34	26	23	35
	4.8	48	2.0	53	18	41	63
	9.7	6.4			10	5.0	9.2
	10	9.0			8	6.0	11
	6.1	11			12	10	13
	3.2	9.1	4.9	14	15	8.5	17
	1.5	13			14	13	16
	0.8	21			16	19	63

TABLE 1 Contd.

	t_{max}	Yield(1)	Transient Flame		Afterglow	
			H_{max}	$Q^{(2)}$	H_{max}	
	(sec)	(kt)	(cal cm^{-2} sec^{-1})	(cal cm^{-2})	(cal. cm^{-2} sec^{-1})	(
Punky Wood, Douglas Fir, (solid)	0.25	65	No ignition for Q = 9.2 cal cm^{-2}			
	0.34	115	15	13	15	
	0.70	480	12	21	12	
	1.1	1,180	13	38	12	
	3.3	10,700	13	108	3.5	
	10.7	110,000	11	287	1.4	
Punky Wood, Douglas Fir (mixed powder and small chunks)	0.25	65	No ignition for Q = 9.2 cal cm^{-2}			
	0.34	115	11	10	11	
	0.70	480			9.3	
	10.7	110,000			0.9	

Notes:

(1) Based on $t_{max} = 0.032\ W^{1/2}$

(2) $Q = 2.6\ H_{max}\ t_{max}$

TABLE 1 Contd.

	Afterglow		Sustained Flame		No. of Specimens Exposed	Range of Radiant Exposures	
(2)	H_{max}	Q(2)	H_{max}	Q(2)		Low	High
m^{-2})	(cal·cm^{-2} sec^{-1})	(cal cm^{-2})	(cal cm^{-2} sec^{-1})	(cal cm^{-2})		(cal cm^{-2})	
2 cal cm^{-2}					3		9.2
	15	13			8	12	13
	12	21			11	19	29
	12	33			13	33	43
	3.5	30			32	28	128
	1.4	37			19	26	399
[illegible] cal cm^{-2}					2		9.2
	11	10			13	8.5	13
	9.3	17			12	13	26
	5.9	25			13	22	32